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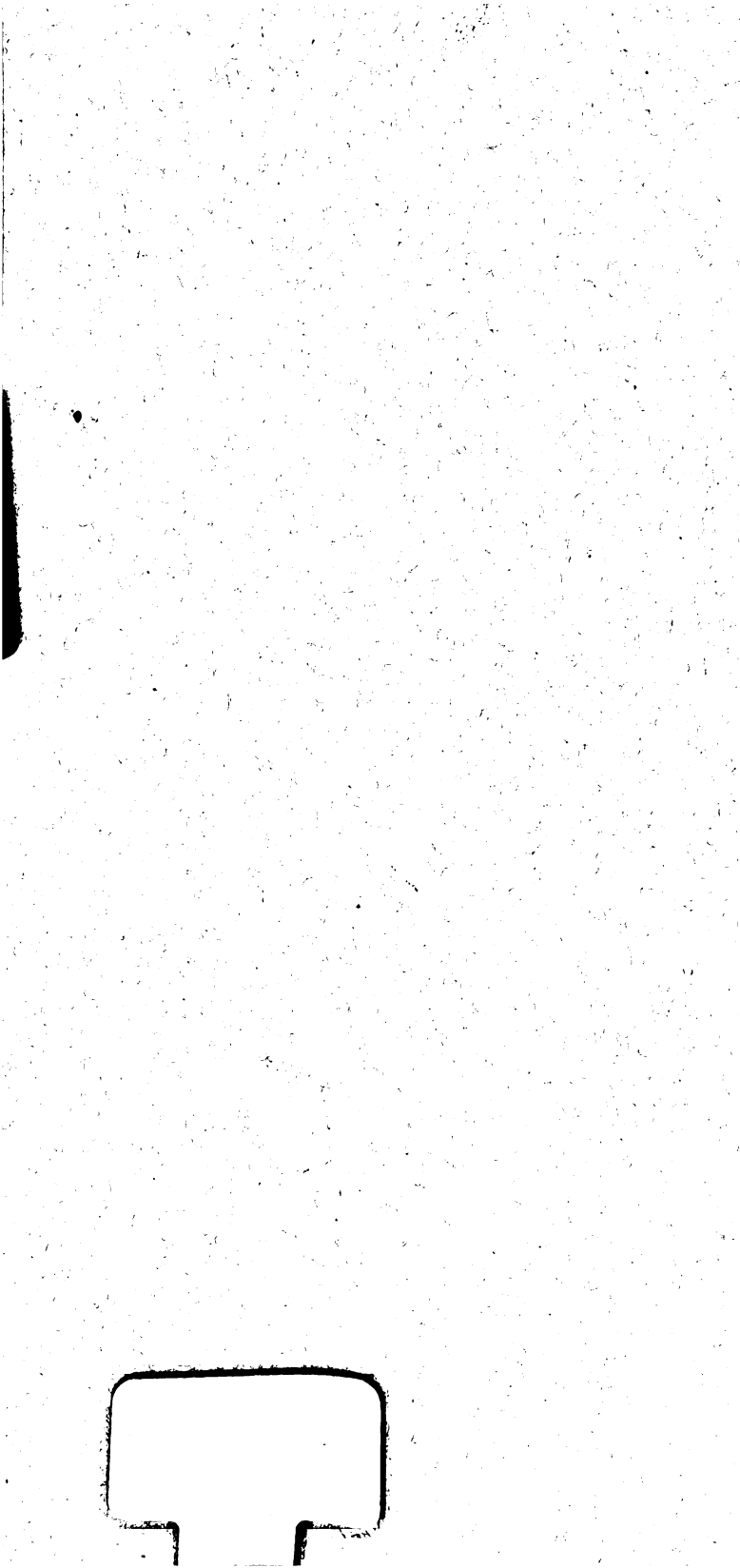
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PURE FOREST OF WESTERN YELLOW PINE, MONTANA, IN WHICH THREE TREES HAVE BEEN
KILLED BY LIGHTNING.

Issued September 12, 1912.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—BULLETIN 111.

HENRY S. GRAVES, Forester.

LIGHTNING IN RELATION TO FOREST FIRES.

BY

FRED G. PLUMMER,

GEOGRAPHER.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1912.

LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
FOREST SERVICE,
Washington, D. C., April 8, 1912.

SIR: I have the honor to transmit herewith a manuscript entitled "Lightning in Relation to Forest Fires," by Fred G. Plummer, Geographer, and to recommend its publication as Bulletin 111 of the Forest Service.

Respectfully,

HENRY S. GRAVES,
Forester.

HON. JAMES WILSON,
Secretary of Agriculture.

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LIGHTNING IN RELATION TO FOREST FIRES.

PURPOSE OF THE STUDY.

That lightning is one of the chief causes of forest fires is now an established fact. Careful observations on the National Forests have shown that there it ranks second only to sparks from locomotives as a source of conflagration. Concerning the liability of trees to lightning stroke, the claimed immunity of some kinds, the susceptibility of other kinds, there has always been an abundance of speculation, and often persistent belief, but very little actual knowledge. It was the aim of the study upon which this bulletin is based to bring together all existing data relating to lightning and trees, and from those that appeared sound, reenforced by the results of observations made upon the National Forests and of laboratory experiments by the Forest Service, to arrive at some definite conclusions regarding the relative frequency with which trees are struck, the conditions which tend to produce the greatest danger, and the relative susceptibility of different forms and species. Until now nothing has been published in the United States on these subjects.

NATURE AND KINDS OF LIGHTNING.

Lightning is a violent discharge of electricity, either between one cloud and another, between a cloud and the earth, or between two strata of air differently electrified. The discharge is commonly assumed to be from a higher to a lower level, although it may be from either or both.

The potential between various air strata, or between air strata and the earth, is variable, and changes in it may be sudden. Clear air is, as a rule, electrified positively, and the same is true of air containing smoke, fog, or falling snow. In rain the electrification ranges from high negative to high positive, but is more often positive. During a single storm the air may change back and forth several times from a positive to a negative condition, and the difference in potential between the earth and a point 10 feet above it may amount to hundreds or even thousands of volts. Considering the surface of the earth as a datum, the potential increases with elevation, but the difference in potential per unit of vertical distance decreases with altitude.

Two principal kinds of lightning are distinguished, *linear* and *ball*. The effects of the first may be peculiarly destructive. Its flashes are followed by thunder and usually accompanied by a downpour of rain. When its light is seen from a great distance, often through clouds near the horizon, it is called *diffused*, *heat*, or *sheet lightning*. The same appearance may, however, be due to actually diffused and silent discharges at great altitudes.

A long flash of linear lightning, if visibly composed of a number of short segments in the same general direction, is called *pearl* or *beaded lightning*. If a streak splits into two or more parts the form is called *forked lightning*. Occasionally it is so branched or sprayed as to resemble the form of a naked tree.

Linear lightning is not considered freakish as a rule, except in some of its effects, yet in rare cases it has struck out of an absolutely clear sky, or has been silent, probably because of intervening atmospheric conditions.

The exact nature of a flash is unknown. Although kite experiments have shown the varying potentials between air strata, and although it is generally held that electricity flows from a positive toward a negative body, still there is evidence that a lightning discharge is, in most cases, pulsating. Photographs have shown not only a number of parallel flashes, which appeared as one flash to the naked eye, but they have also shown the flash to have width, like a ribbon. It seems that a flash, even if lasting only a thousandth part of a second, may be composed of a large number of separate flashes having much smaller duration.

It has been held that a lightning stroke differs according to the direction of the flash; as to whether the earth is negative or positive; that although flashes are most common between differently electrified clouds, or from a cloud to the earth, still they also ascend from the earth into the air. The violence of the discharge and its effects are matters of pressure or tension between the earth and a cloud or a person, or indeed between one person and another at the time. After a discharge there is sometimes an adjustment of potentials known as "choc de retour."

Ball lightning is also called *fire ball* and *globular lightning*, and sometimes, loosely, *thunderbolts*. Balls may vary from a half inch to several feet in diameter. They differ in form and motion from linear lightning, but as both kinds are erratic their effects are sometimes similar. Balls of lightning may come from any direction, may move slowly or rapidly, and may be harmless or deadly. They float through open windows or doorways and up chimneys. They may play around a lightning rod without being attracted, or may strike the ground and rebound without being dissipated. It would be difficult to believe, as some maintain, that such an outlaw could not set fire to a tree.

Ball lightning should not be confounded with St. Elmo's light or St. Elmo's fire, the *corpo santo*, a blue or red¹ electric discharge sometimes seen on the masts and yards of ships at sea, and more rarely on church spires and trees, and points of rock on land, or about the heads of persons. Nor should it be confused with the *ignis fatuus*, elf-fire, will-o'-the-wisp, or jack-o'-lantern, a self-luminous glow sometimes seen at night in marshes or swamps.

EFFECTS OF LIGHTNING ON TREES AND SOIL.

The present discussion considers only the relation of lightning to forests, and will be restricted to the effects of lightning upon trees and soils.

Regarding the effects of lightning, Seneca wrote:

The stronger bodies are shattered with greater violence on account of their resistance, it sometimes passing through the yielding one without doing any damage. . . . In a tree it scorches any portion that is very dry; what is firm and hard it bores through and smashes; the outer bark it scatters, the inner layers nearer the center it bursts and cuts up, the leaves it lashes and strips off.

Any lightning flash may be destructive or fatal.

¹ It is assumed that the color indicates the electric sign of the emanation; that it is blue if negative and red if positive.



FIG. 1.—Western yellow pine, southern California, struck, split, and likely to die.

The phenomena attending such flashes may differ widely, and it has been assumed that this difference is due to the direction of the flash. In other words, it makes a difference whether the object was electrified positively or negatively; whether the flash was toward or away from it. The electric flash is so sudden that the eye can not catch the direction. In the case of forked lightning, however, the direction may be inferred from the appearance of the phenomenon.

The same flash may strike and blast a number of trees, and the results may be quite as curious and erratic as the lightning itself. A tree may be scorched, it may be stripped of its leaves, it may be cleft longitudinally, or, more rarely, severed horizontally. Pieces of bark or wood may be torn off in strips. One-half of a tree's crown may be withered, the other half remaining unharmed. Sometimes the bark is stripped from only one side, occasionally without a trace of burning; at other times it may be riddled, as by worms, with a multitude of little holes. The lightning furrow on a tree is usually single; but it may be double, usually in parallel lines. Furrows may be oblique or spiral, the current in such cases following the grain of the new wood. If the tree is inflammable or is rendered very dry by the flash a fire may result. In other cases the dry duff or humus at the base of the tree is ignited by the flash.

The action of the flash in stripping bark from a tree is a subject still open to discussion. It may be argued, on the one hand, that the moisture contained along the line of the flash is instantly converted into superheated steam, or that the water is converted, by electrolysis, into its component gases, and that the suddenly increased volume causes a rupture. On the other hand, it is held that the flash requires an open channel for its passage, and mechanically splits off the bark. The fact that it can follow the longitudinal fibers of a tree would seem to support this idea, as would also the phenomena of fulgurites, to be mentioned later.

It seems probable that the wood immediately in and around a superficial wound produced by a stroke of lightning would show at least some structural disturbance, such as the rupture of cell elements, etc., that could readily be seen under the microscope. A structural study of such wood, however, recently made by the Dendrological Laboratory of the Forest Service shows that lightning produced no visible effect upon the tissue.

A flash of lightning striking upward through the tree from its base acts as an explosive. The trees may then be torn into small fragments, and cases have been recorded where these appeared like a piece of hemp. If the upward flash is less violent, the trees may be split radially. The tops of trees have been torn off while the lower parts remained uninjured. On the other hand, the lower portion of

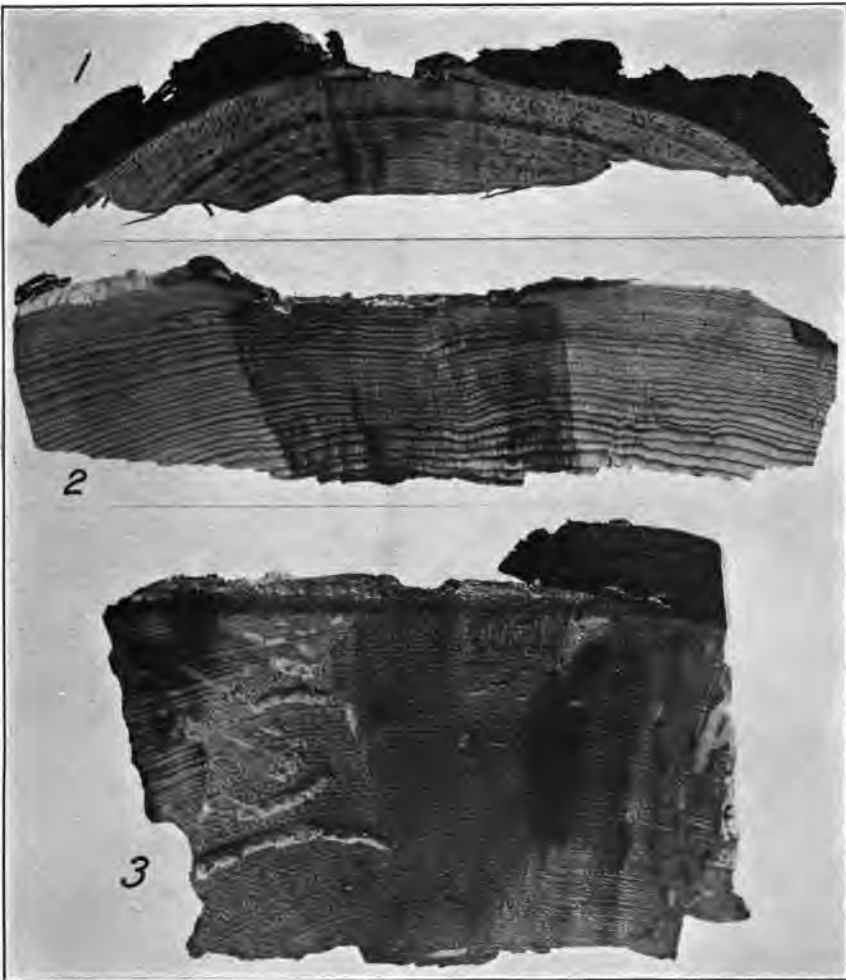


FIG. 1.—CROSS SECTION OF SUPERFICIAL WOUND ON WESTERN YELLOW PINE, PARTLY HEALED BY 11 YEARS' SUBSEQUENT GROWTH. FIG. 2.—CROSS SECTION OF SUPERFICIAL WOUND ON WESTERN YELLOW PINE, SLIGHTLY HEALED BY 7 YEARS' SUBSEQUENT GROWTH. FIG. 3.—CROSS SECTION OF LIGHTNING WOUND ON WESTERN YELLOW PINE; TREE DIED.





FIG. 2.—Isolated western yellow pine, Colorado, dismantled and killed.

a tree has been demolished, while the upper part fell to the ground intact.

Lightning often strikes twice or more than twice in the same place. Some trees favorably located for attracting the flash bear seven or eight scars, all visible, and determined by a stem analysis of the trunk. The same is true regarding some rocky summits and buildings. Out of 907 cases recorded by one observer, 21 were repeated strokes on trees and buildings.

It has been held, though not proven, that the bigtrees of California are repeatedly struck by lightning, and that although not killed, their leaders are broken and their tops stunted in consequence. The form of their boles and the shape of their crowns would seem to favor this belief. Although giants, their heights are much lower than would be expected from the taper of their boles.

The effect of lightning on the ground is as remarkable as its effect upon trees. It may enter the ground without disturbing it or heat-

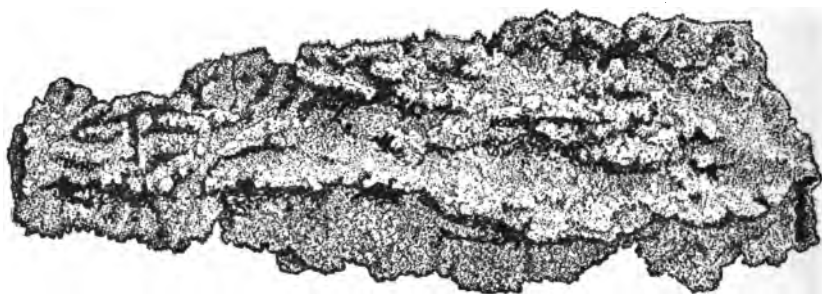


FIG. 3.—Section of fulgurite formed in sand by lightning.

ing it, or it may tear large holes or melt the surface. Although lightning usually strikes the ground with a vertical stroke, it sometimes comes obliquely or almost horizontally, plowing long furrows. Sometimes it tears a circular or funnel-shaped hole, and, when striking sand, forms fulgurites.¹ These are hollow tubes, formed of the fused materials, and may vary from one-half inch to 6 inches in diameter. Fulgurites may extend 25 feet into the earth, and be vitrified or glassy on the inside, and coarse grained or half fused on the outside. Sometimes the fulgurite has the form of an inverted tree with numerous branches and branchlets.

When lightning strikes solid rock it may either enter the mass and form a fulgurite tube, or it may be diffused over its surface, according to the conductivity of the formation. In one case it may split the material into large or small pieces, or it may fuse the surface, giving it a vitreous coat, usually with nodules or blisters. When these

¹ Also called thunderbolts, thunderstones, stormstones, Thor's bolts, and ceraunia.



FIG. 4.—Western yellow pine, Oregon, killed by lightning, showing spiral wound.

phenomena are seen on high summits or prominent points they may be considered evidence of lightning strokes. The presence of metals in the earth increases the danger of the stroke, and it is probable that veins of metal favorably situated will protect surrounding nonmetallic areas.

It has often been stated that the majority of persons killed by lightning sought refuge under trees, but this is not the fact. More than one-half of such deaths occur in the open, and less than one-quarter under trees.

SUPPOSED LIABILITY OF TREES TO LIGHTNING STROKE.

EARLY AND PRESENT BELIEFS AND THEORIES.

From early times there has been a belief that certain trees more than others are likely to be struck by lightning. The elder Pliny said: "Lightning never strikes the laurel." This tree (*Laurus nobilis*) was also called bay, and wreaths of its leaves were worn by ancient rulers both as a symbol of victory and as a protection from the lightning of the gods. Seneca and Plutarch held a similar belief, which may be traced down even to modern times, but the theory as now held includes a number of trees, differing in various countries. This belief was so firmly established that such trees as the beech and locust, supposed to be effective in warding off lightning,¹ were planted near dwellings.

To this day there are many who still insist that the beech is never struck, while in parts of the United States the aspen is considered immune from lightning.

On the other hand, it was believed that such trees as the oaks, particularly cork oak, had a very bad reputation for attracting lightning, and this belief prevails even now. There is a proverb—

Avoid the oak, flee from the spruce, but seek the beech.

And also:

Beware the oak, it draws the stroke.

Avoid the ash, it courts the flash.

Creep under the thorn, 'twill save from harm.

Natives of South Africa have said regarding the mopane tree, which is often struck, "Lightning hates it"; but they say that the morala tree is never touched. The Portuguese share this belief.

There was once a widespread belief in Europe that conifers were almost immune from lightning, but records made there showed that conifers rank third in liability to stroke. The persistent popular

¹ Holly, olive, walnut, birch, elder, mistletoe, and live-for-ever have been considered immune from strokes.

beliefs regarding immunity of some trees and liability of others have given rise to the following theories regarding trees most likely to be struck:

1. Tall trees.—Because they reach high toward the electrically charged cloud, and therefore lessen the distance which the flash must traverse through the dielectric (air). Such trees are conceived to be a part of the earth, extending upward and inviting the stroke.

2. Trees with pointed crowns.—Because they invite, to their one apex, a single full-pressure flash. Trees with rounded crowns favor the diffusion of the flash into a spray.

3. Trees with pointed leaves.—Because static electricity jumps most easily to and from pointed terminals.

4. Trees with smooth or shiny leaves.—Because a smooth surface invites flashes, while a hairy or woolly surface, presenting a multitude of fine points, favors diffusion.

5. Trees with deeply grooved bark.—Because bark deeply grooved longitudinally guides the current to the ground, and because the moist sapwood is close to the surface in the bottoms of the fissures.

6. Trees isolated.—Because they are the only marks for the flash and are conductors.

7. Trees on high ground.—Because they are nearest to the storm-cloud strata.

8. Trees on damp soil.—Because the moisture makes a good contact between the tree and the earth.

9. Trees deeply rooted.—Because the long roots give a better grounding and furnish a more direct path to deeper and moister earth strata.

10. Trees with dead branches.—Because they present alluring points.

11. Trees whose wood has high electric conductivity.—Because the flash will select the path of least resistance.

12. Trees whose tissues are composed mostly of longitudinally arranged fibers and other elements.—Because this arrangement would favor the transmission of the electric current.

13. Trees rich in starch.—Because starches and sugars are better conductors than oils, resins, and waxes.

EUROPEAN INVESTIGATIONS.

Table 1, compiled from 3,136 cases observed in Belgium, France, Germany, Holland, and other European countries, shows the relative frequency with which different kinds of trees were struck by lightning in the regions studied.

TABLE 1.—*Percentage of different species struck by lightning in Europe.*

Kind of tree.	Per cent.	Kind of tree.	Per cent.
Poplar.....	30.5	Horse chestnut.....	0.3
Oak.....	20.7	Plum.....	.3
Conifers.....	15.5	Alder.....	.2
Elm.....	4.6	Larch.....	.2
Pear.....	3.9	Service.....	.2
Willow.....	3.5	Catalpa.....	.1
Beech.....	2.4	Elder.....	.1
Ash.....	1.8	Lime.....	.1
Linden.....	1.8	Maple.....	.1
Walnut.....	1.3	Vine.....	.1
Cherry.....	1.2	Others.....	.4
Apple.....	1.0	Unknown.....	8.0
Chestnut.....	.8		
Birch.....	.5		
Acacia.....	.4		100.0

Data have been gathered both in Europe and in the United States on the frequency of lightning stroke upon trees growing in different soils. An average of all results shows the relative percentages to be:

	Per cent.
Loam.....	42
Sand.....	22
Clay.....	19
Others, including rock, marl, and calcareous formations.....	17
	100

This comparison does not take into account the relative areas of the different soils covered in the investigations. A fairer estimate, made in Belgium, and reduced to actual frequency per unit area, gives the following:

	Per cent.
Loam.....	23
Sand.....	18
Clay.....	17
Others.....	42
	100

The frequency of stroke upon the poplar growing in these soils was:

	Per cent.
On loamy soil.....	28
On sandy soil.....	24
On clay soil.....	6
On other soils.....	42
	100

Du Moncel demonstrated¹ that the conductivity of wood is governed by its moisture content and its temperature, and also that electricity traverses wood more easily in the longitudinal direction of its fibers than across them. Table 2, prepared by him, shows the deflec-

¹ Th. du Moncel, *Recherches sur la conductibilité électrique des corps médiocrement conducteurs et les phénomènes qui les accompagnent.* Annales de Chimie et de Physique, p. 471, Paris, 1877.

tions, in degrees, of a galvanometer needle for 19 specimens of woods when dry and when containing different amounts of moisture.

TABLE 2.—*Conductivity of wood under different moisture contents as determined by du Moncel.*

Kind of wood.	Deflection of galvanometer needle—degrees.				
	As received from the carpenter.	After 2 hours in the oven.	After 2 hours in the humidior.	After 5 hours in the humidior.	After 15 hours in the humidior.
Linden.....	87	0	10.0	24.0	43
Ebony.....	86	0	75.0	80.0	14
Apple.....	86	4, then 0	3.0	3.0	10
Chestnut.....	85	5, then 0	9.0	12.5	48
Poplar.....	85	0	27.0	44.0	17
Laburnum.....	79	0	10.0	16.0	8
Common box.....	76	5, then 0	22.0	35.0	17
Cedar.....	71	0	23.0	37.5	14
Red fir.....	62	0	12.0	20.0	18
Sycamore.....	56	5, then 0	6.0	10.0	11
Acacia.....	55	0	14.0	18.5	10
Virginia cedar.....	51	5, then 0	6.0	7.0	9
Willow.....	50	5, then 0	10.0	21.0	15
Elm.....	48	0	9.0	13.0	35
Yew.....	46	4, then 0	8.0	9.0	10
Walnut.....	45	4, then 0	9.0	12.0	15
Beech.....	38	0	7.5	10.5	30
White fir.....	32	5, then 0	8.0	11.0	25
Oak.....	32	5, then 0	3.0	3.0	9

The deflections which occurred at first in some of the specimens dried two hours in an oven were doubtless due to the presence of a small amount of moisture in the wood, which was later dissipated by the heat from the electric current passed through the specimens. As the moisture was driven out the deflection fell to zero. Exactly the same change was observed in experiments made by the Forest Service.

Very few experiments have been made to determine the dielectric constants for woods, giving their specific inductive capacity as differing from their conductive function. The results of experiments by Winkelmann are given below.¹ The specimen of wood was considered as an insulator and placed between the plates of a condenser, the capacity of which was then measured. This capacity divided by the capacity when dry air only was between the plates equals the dielectric constant. The determinations, assuming a value for dry air of 1, were:

Oak, parallel to grain.....	2.46 to 4.22
Oak, across grain.....	3.64 to 6.84
Fir (Tanne).....	2.95
Beech, parallel to grain.....	2.51 to 4.83
Beech, across grain.....	3.63 to 7.71

¹ Winkelmann, *Handbuch der Physik*, Vol. IV, pp. 98-148. Breslau, 1905.

VALUE OF THEORIES AND DATA.

If theories 1, 2, 3, and 4 be considered together, they seem to agree with the foreign statistics regarding the liability of poplars to lightning stroke, these trees generally having smooth pointed leaves and some of them rather pointed crowns. But *Populus monilifera* (a North American tree planted in Europe), the species most often struck, has naturally a rounded crown. Moreover, the theories do not agree when applied to oaks, which have comparatively low and rounded crowns, although some oaks have leaves which are smooth on the upper surface, or to elms, which have rounded crowns and hairy or scarcely smooth leaves. They agree, however, in the case of most conifers.

If theories 6, 7, 8, and 9 be considered together, some conflicts may be noted. If trees are upon high ground, and therefore nearer the clouds, they are not likely to be upon damp soils, which are common in the flats and valleys. Trees upon damp soil are not likely to be isolated, except when left standing after logging or in cultivated fields or pastures. Trees on high ground will naturally be deep rooted, but not those on lowland damp soil. Cottonwood, a moisture-loving tree, prefers valleys, and has a superficial root system, and yet it is held by European investigators to be most liable to lightning stroke. Regarding theory 6 alone, it is obvious that if trees are closely massed, their crowns forming an even cover, the conditions are favorable for dissipating and grounding an electrical discharge. The reverse is, of course, true when trees are in open stand or scattered.

Theories 10, 11, 12, and 13 may also be considered together, for 10 and 11 assume that dry wood is a conductor of electricity, 13 assumes that some secretions of the woods are the conductors, and 12 assumes that the structure of the wood and, consequently, the form of the secretions favor electric transmission. This raises the much discussed question—is conductivity entirely dependent upon the water content of the wood? Jonesco¹ believed that the amount of water in trees has no effect on their liability to stroke, but that the presence of dead branches increases the likelihood. Vanderlinden² held that there is nothing to prove that conductivity to lightning is dependent upon the form, anatomical qualities, or chemical composition of the wood, while Flammarion³ thinks the liability depends upon the sap.

Regarding theory 13, it may be assumed that the water content of any wood, and therefore its conductivity, will depend largely upon whether its secretions are soluble or insoluble in water. Thus, trees

¹ Jonesco, Ueber die Ursachen der Blitzschläge in Bäume, Stuttgart, 9, 62. 1893.

² Vanderlinden, La Foudre et les Arbres. Annales de L'observatoire Royal, n. s., Annales météorologiques, tome 20, p. 25. Bruxelles, 1907.

³ Flammarion, Thunder and Lightning, p. 157. 1906.

rich in fatty materials, such as oils, glycerides, resins, and waxes, should be poor conductors of electricity, and trees rich in starchy materials,¹ such as are soluble in water, should be good conductors of electricity. Unfortunately, such a classification does not distinguish species, nor even genera, although coniferous trees are generally very fatty, while broadleaf trees generally contain large amounts of starch.

Dr. Albert Fischer's² investigations may be applied to this theory, as he grouped 36 European trees according to their secretions during the lightning months, June to September. His classification is as follows:

Rich in starch (Glycosereich):

European alder.	European red-osier dogwood.
White birch.	European spindle tree.
European hazel or filbert.	Buckthorn.
Hornbeam.	Lilac.
European aspen.	Pear.
Field maple.	Apple.
Silver maple.	Sweet cherry.
Norway maple.	Garden plum.
Sycamore maple.	Small bird cherry.

Moderately rich in starch (Ziemlich glycosereich):

Ailanthus.	Elder.
Privet.	Wild olive.

Poor in starch (Glycosearm):

European oak.	European rowan-tree.
English elm.	Bladder-senna.
Tamarisk.	Laburnum.
Horse chestnut.	Locust.
Linden.	Japanese catalpa.
Hawthorne.	

Free from starch (Glycosefrei):

European ash.	Circassian walnut.
---------------	--------------------

Comparing these results with the statistics of trees struck in Europe, there are more conflicts than agreements with the theory. Cottonwood, the tree most often struck, is not classified, but European aspen (*Populus tremula*), classified as "rich in starch" and therefore liable to stroke, corresponds to our native aspen (*Populus tremuloides*), a tree rarely struck, even in the lightning zones. The European oak, the only oak mentioned, is classified as "poor in starch," yet in the statistics oak ranks second for liability. English elm (*Ulmus campestris*), the only elm mentioned, is classified as

¹ Schimper, Plant Geography upon a Physiological Basis, p. 436. Oxford, 1903. Warming, Ecology of Plants, p. 23. Oxford, 1909. Jonesco, Ueber die Ursachen der Blitzschläge in Bäume, p. 33. Stuttgart, 1893.

² Jahrbücher für wissenschaftliche Botanik, Herausgegeben von Dr. N. Pringsheim, p. 75. Berlin, 1891.

"poor in starch," yet elm ranks fourth in liability to lightning stroke according to the European statistics. On the other hand, the four maples classified by Fischer as "rich in starch" should be most liable to stroke, yet general statistics show that in this respect maple ranks with the lowest. Conifers are not classified.

INVESTIGATIONS IN THE UNITED STATES.

During the past five years the Forest Service has gathered on the National Forests full and comprehensive data regarding the number of fires caused by lightning, the kind of trees most often struck, the proportion of those struck which ignite, and the like. Observations were made by nearly 3,000 Forest officers, and covered a territory of nearly 200,000,000 acres, an area greater than Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, and Ohio taken together, or about equal to Norway and Sweden combined. In addition to the field observations, laboratory experiments were made with native woods to determine their electric conductivity. Records of the United States Weather Bureau have furnished data on the distribution and frequency of thunderstorms.

GEOGRAPHIC DISTRIBUTION OF LIGHTNING.

In temperate climates thunderstorms, with lightning, occur most commonly during the summer, usually in the afternoon. In the United States they are four or five times as frequent east of the Rocky Mountains as west, omitting from consideration parts of Arizona and New Mexico. This is due, as explained later, to the generally mountainous condition of the West. Lightning is most frequent in Florida and Illinois.

As might be expected, even though lightning is less common in the West than in the East, the proportion of fires which owe their origin to lightning is much greater on the National Forests than in the thickly settled portions of the country. In the former case it is, for trees only, 17.5 per cent; in the latter, for all objects, about 2.5. This difference is largely due to the fact that risk from lightning is much greater in unsettled country than in cities, towns, and their vicinity. Forests on mountain slopes and summits are particularly exposed, while houses and other structures liable to stroke are usually protected by lightning rods. Moreover, the form of all trees—spreading branches in the air, spreading roots in the soil—is practically identical with that of the most efficient type of lightning rod, which has a number of branches at both its upper end and at the end in the soil.

LIGHTNING ZONE.

Throughout the Cordilleran region of the West there are certain areas which, because they have a marked hazard from lightning, are said to be in the lightning zone. These areas, several hundred of

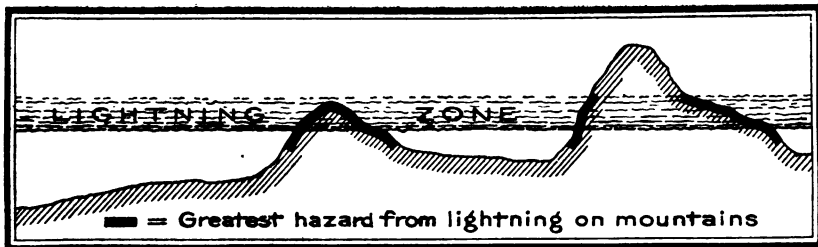


FIG. 5.—Lightning zone in mountainous country.

which have been mapped, usually lie in or near National Forests, and are therefore considered in the present study.

A lightning zone is conceived to be a layer of the lower atmosphere—a thundercloud stratum, which touches the summits of some moun-

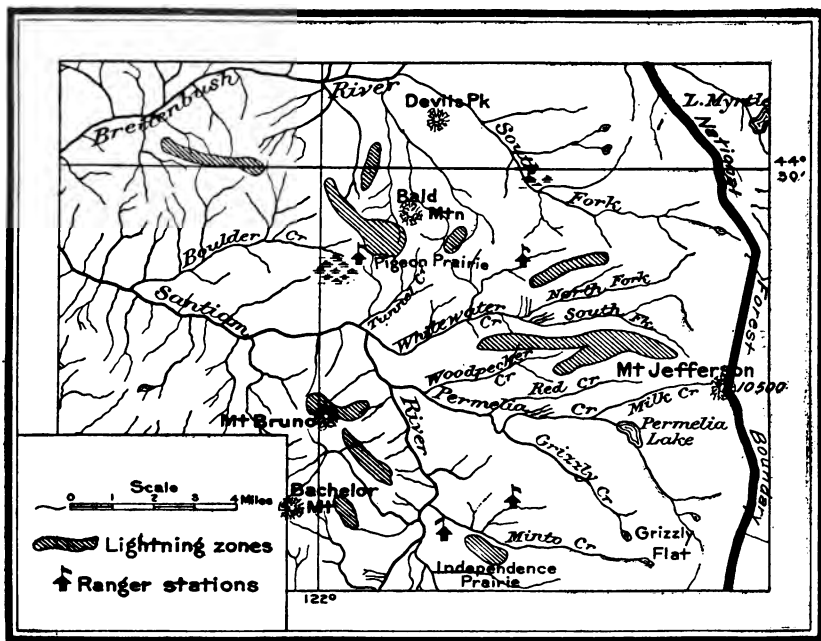


FIG. 6.—Lightning zones in a portion of Santiam National Forest, Oregon.

tains and the lower slopes of others (figs. 5 and 6). The altitude of the zone varies, for it is subject to modulations just as are other atmospheric strata "flowing" over or around high points.

RECORD OF TREES STRUCK AND SET ON FIRE BY LIGHTNING.

Records of observations on trees struck by lightning on the National Forests are not uniform in all respects. About 40 per cent of the observers gave, for a stated length of time and on a certain area, the exact number of trees of each species struck, while about 58 per

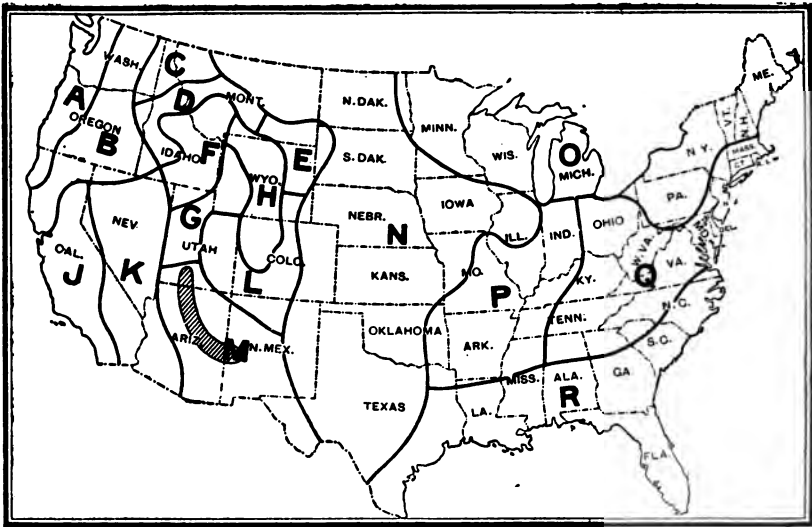


FIG. 7.—Regions of the United States in which certain trees seem most liable to lightning stroke.

cent recorded the number of trees struck and gave a list of the species in the stand in order of their importance. Two per cent listed the species in the order of liability, but were unable to give the number of trees struck. It was possible, however, by interpolating, to prepare estimates not only showing in proper order the species struck, but also approximating very closely the per cent of each.

The accuracy of such estimates is further assured by dividing the country into regions, where the reports have indicated similar conditions. These regions, shown in figure 7, are designated by A, B, C, etc.

TABLE 3.—*Number of trees reported struck by lightning on the National Forests—with percentage of each species.*

Region. (See map, fig. 7.)	Average time covered by all reports.	Total trees reported struck.	Western yellow pine.	Douglas fir.	White fir.	Engelmann spruce.	Lodgepole pine.	White-bark pine.	Blue spruce.	Alpine fir.	Piñon.
	<i>Years.</i>	<i>Number.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
A.....	3	795	19.1	28.9	12.1	1.4	1.4	.....	.....	.....	.....
B.....	4	9,149	72.4	2.1	10.0	.....	7.3	.....	.....	.....	.....
C.....	4	490	22.5	18.2	1.0	.....	1.6	.....	.....	.....	.....
D.....	3	1,745	38.3	26.9	6.2	3.4	10.2	3.8	.....	.....	.....
E.....	3	1,587	98.5	.....	.....	.....	.....	.....	.....	.....	.....
F.....	3	8,441	22.7	31.7	12.1	4.6	10.4	16.5	.....	.....	.....
G.....	6	480	2.5	22.1	.....	4	10.4	10.8	.....	44.0	0.8
H.....	3	1,161	6.2	7.0	.....	25.7	25.0	.....	1.2	10.4	1.3
I.....	3	3,912	27.5	2.0	33.1	.....	2.7	.....	.....	.....	.....
J.....	2	23	.....	.....	.....	.....	.....	.....	.....	.....	.....
K.....	4	6,437	49.7	.....	.....	6.9	1.5	.....	.....	.....	.....
L.....	3	42,081	63.1	18.0	8.0	2.4	.....	.....	2.5	4.9	1.8
M.....	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total.....	41	76,301	55.0	17.0	9.6	3.0	3.0	1.9	1.4	1.3	1.0

Region. (See map, fig. 7.)	Average time covered by all reports.	Total trees reported struck.	Red fir.	Mexican white pine.	Western juniper.	One-seed juniper.	Sugar pine.	Lumber pine.	Aspen.	Western larch.	Emory oak.
	<i>Years.</i>	<i>Number.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
A.....	3	795	.....	.....	.....	.....	8.2	.....	.....	.....	.....
B.....	4	9,149	.....	.....	6.4	.....	4	.....	.....	0.6	.....
C.....	4	490	.....	.....	.....	.....	.....	.....	.....	31.7	.....
D.....	3	1,745	.....	.....	.....	.....	.....	7.2	0.5	1.7	.....
E.....	3	1,587	.....	.....	.....	.....	.....	.....	.....	.....	.....
F.....	3	8,441	.....	.....	.....	.....	.....	.....	.....	.....	.....
G.....	6	480	.....	.....	.....	.....	.....	.....	.....	.....	.....
H.....	3	1,161	.....	.....	.....	7.6	.....	6.5	1.7	.....	.....
I.....	3	3,912	18.3	.....	.....	.....	7.1	1.1	14.5	.....	.....
J.....	2	23	.....	.....	.....	.....	.....	.....	.....	.....	.....
K.....	4	6,437	.....	.....	.....	.....	.....	.....	.....	.....	.....
L.....	3	42,081	.....	.....	.....	.....	.....	.....	.....	.....	.....
M.....	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total.....	41	76,301	.9	.9	.8	.7	.5	.4	.4	.3	.2

Region. (See map, fig. 7.)	Average time covered by all reports.	Total trees reported struck.	Alligator juniper.	White pine.	Jeffrey pine.	Bristle-cone pine.	Blue oak.	Western hemlock.	Shasta fir.	Narrowleaf cottonwood.	Utah juniper.	Others.
	<i>Years.</i>	<i>No.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
A.....	3	795	.....	3.7	.....	.....	.....	6.5	.....	.....	.....	12.3
B.....	4	9,149	.....	.1	0.2	.....	.....	.....	.....	.....	.....	.3
C.....	4	490	.....	15.7	.....	.....	.....	.....	.....	.....	.....	6.7
D.....	3	1,745	.....	.1	.....	.....	.....	.....	.....	.....	.....	.7
E.....	3	1,587	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.4
F.....	3	8,441	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
G.....	6	480	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
H.....	3	1,161	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
I.....	3	3,912	.....	.8	3.4	.....	.....	.....	.....	.....	.....	.....
J.....	2	23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
K.....	4	6,437	.....	.....	.....	1.3	.....	.....	.....	.....	.....	.....
L.....	3	42,081	0.3	.....	.....	.....	0.2	.....	.....	0.8	.....	.....
M.....	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total.....	41	76,301	.2	.2	.2	.1	.1	.1	.1	.1	.1	.5

× = Represented.



FIG. 8.—Western yellow pine, Lower California, dismantled and ignited by lightning.

According to present information, only about 2 per cent of the trees struck by lightning on the National Forests are ignited. The order in which the western trees are likely to be ignited is shown in the following list. Trees struck oftenest, however, are not necessarily the chief source of fires started by lightning.

In region A:

- Douglas fir.
- Western yellow pine.
- Western white pine.
- Western hemlock.
- Noble fir.

In region B:

- Western yellow pine.
- White fir.
- Douglas fir.
- Lodgepole pine.
- Western juniper.

In region C:

- Western yellow pine.
- Western larch.
- Douglas fir.
- Western white pine.
- Western hemlock.

In region D:

- Western yellow pine.
- Douglas fir.
- White fir.
- Engelmann spruce.
- Lodgepole pine.

In region E:

- Western yellow pine (dead).
- Western yellow pine (green).
- In certain areas the fire hazard is greater than in others. Near Cave Hills the lightning usually strikes the exposed cap-rock rather than the trees.

In region F:

- Douglas fir.
- Western yellow pine.
- Lodgepole pine.
- Engelmann spruce.
- Limber pine.

In region G:

Alpine fir.
Douglas fir.
Engelmann spruce.
Limber pine.
Aspen.

In region H:

Engelmann spruce.
Lodgepole pine.
Western yellow pine.
Douglas fir.
Aspen.

In region J:

Western yellow pine (including Jeffrey pine).
White fir.
Red fir.
Sugar pine.
Douglas fir (including bigcone spruce).

In region K:

Thunderstorms are rare; trees are scattered but have been ignited.

In region L:

Western yellow pine.
Douglas fir.
Lodgepole pine.
Engelmann spruce.
Aspen.

In region M:

Western yellow pine (dead).
Western yellow pine (green).
Douglas fir.
White fir.
Engelmann spruce.
Mexican white pine.

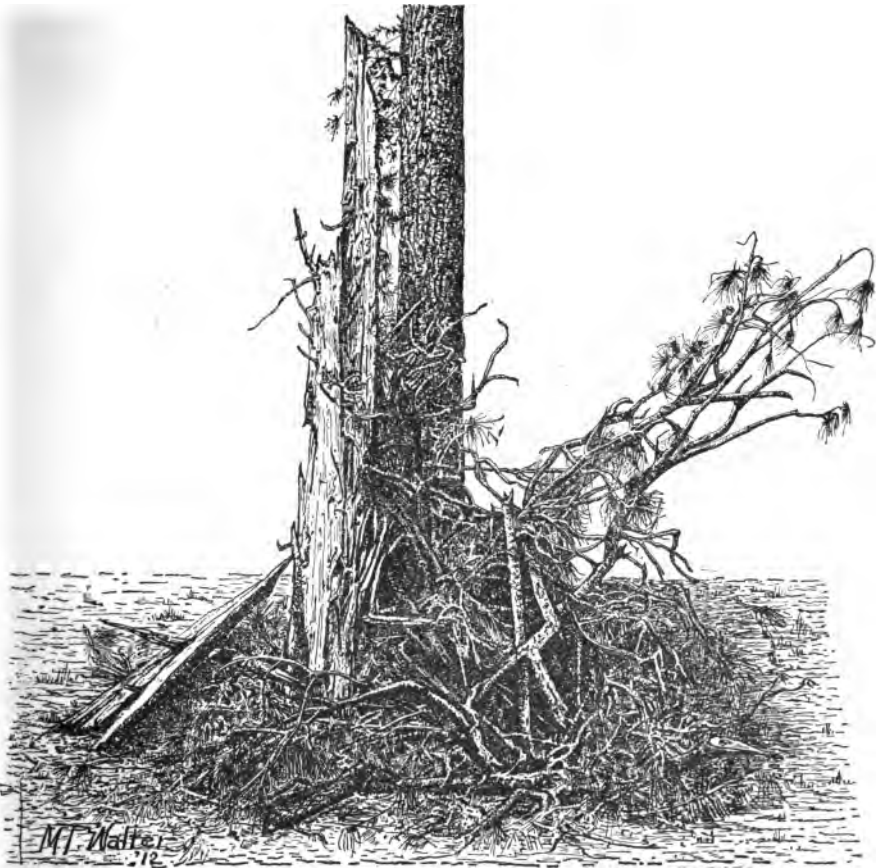


FIG. 9.—Western yellow pine, Arizona, completely shattered by lightning.



FIG. 10.—Chestnut oak, eastern Tennessee, severely wounded and ignited, but partly healed.



FIG. 11.—Western yellow pine, wounded; and Douglas fir, shattered by lightning, Colorado.

In addition to the trees just enumerated, the following species occurring in regions A to M have been struck and ignited by lightning:

Amabilis fir.	Gray pine.
Arizona cork fir.	Cottonwood.
Lowland fir.	Fremont cottonwood.
Noble fir.	Gambel oak.
Boxelder.	California white oak.
Yellow cedar.	Bur oak.
Arizona cypress.	Redwood.
California juniper.	Red cedar.
Utah juniper.	Black hemlock.
Incense cedar.	Joshua-tree.
White spruce.	Piñon.
Foxtail pine.	

More trees are struck by lightning in region M, at least in one part of it, than in any other region of the United States, and in spite of the fact that comparatively more thunderstorms occur in regions N, O, P, Q, and R. This region (M, fig. 7) is a portion of the Colorado Plateau, extending from western New Mexico to southern Utah, crossing the Grand Canyon, and including the White Mountains, Black Mesa, and San Francisco and Sevier Mountains.

Over 60 per cent of the trees struck in this region are western yellow pine (*Pinus ponderosa*). But 85 per cent of the stand there is of this species. Indeed, if this tree did not grow mainly in the lower flat and foothills country, while the lightning zone extends higher and includes other species, the percentage of yellow pine struck by lightning doubtless would be greater. In some sections of this region, as, for example, on the volcanic cinder flats east of San Francisco Mountain, one-half of the mature trees have been killed or injured by lightning. Lightning strokes are of great frequency also on a small part of the Zuni Plateau (in the same region).¹

The data for regions N to R are fragmentary, and it is therefore impossible to estimate, even roughly, the number of trees struck in any area. However, the number of forest fires caused by lightning can be tentatively given, and also the species of trees most liable to stroke.

Region N is naturally treeless, except for the moisture-loving species which fringe the watercourses, and a few upland species on iso-

¹ The following note from the report of Assistant Ranger Miller, who is in charge of the Fort Wingate district, is of great interest in this connection:

"I counted 100 trees on a small area close to Redrock that were struck within the last three or four years. Twenty trees were struck during one afternoon on 20 acres southeast of Redrock. Three spike tops almost dead, were struck one afternoon and all set on fire. I find that many trees are struck in ravines as well as on the ridges. Five trees were struck last year in Foster Canyon below the rim rock and close to water. Two of these trees were small 'blackjacks.' A year ago last September lightning struck a dead snag west of the Reardon mill and set it on fire. Last July the only flash of lightning during a storm struck a dead tree near Sawyer and set fire. Where Douglas fir and yellow pine grow together, one seems to be struck about as often as the other. I have counted only five piñon struck by lightning. Nearly every tree for long distances along the Guam and Redrock telephone has been struck, starting where the wire is fastened to the trees. The lightning jumps the wire and runs down the trees."

lated areas, the largest of these being the Wichita Mountains, Okla. The fire hazard from lightning is very small, only 26 fires being attributed to it during 4 years. The trees most liable to stroke are jack pine, post oak, and poplar.

In region O about 70 fires are caused yearly by lightning. In 1911 130 trees were struck on three National Forests, which cover about 1,000,000 acres in Michigan and Minnesota. The trees most liable to stroke are Norway pine, white pine, and tamarack. Hemlock, spruce, white oak, birch, ash, maple, and beech are also reported struck.

In region P the only reliable record of forest fires caused by lightning is from Arkansas, where the yearly average is 3 fires. About 90 trees were struck during 1911. The trees most liable to stroke are white oak, black oak, red oak, Spanish oak, black walnut, and several species of hickoria. Hemlock, maple, ash, sycamore, beech, elm, and Norway pine are also reported.

In region Q forest fires are seldom caused by lightning, except in the mountainous portions of North Carolina and Massachusetts, yet notwithstanding this all reports indicate that trees are struck very often, particularly in the Appalachians. Chestnut easily leads in the liability to stroke and is closely followed by several species of quercus and pinus; the beech is struck, but not often. Yellow poplar is often reported.



FIG. 12.—Chestnut, North Carolina, showing typical spiral wound, partly healed, on living tree.

In region R the heavy rains which accompany lightning make the fire hazard from this source very small. Occasionally dead pines on the coastal plain are set on fire by lightning, and in 1910 one forest fire resulted in Florida. Thunderstorms are frequent and severe in



FIG. 13.—Lightning wound on cottonwood, Iowa.

this region, and a conservative estimate would place the number of trees struck yearly at 30,000. Longleaf pine is most liable to stroke, and next are the shortleaf and the Cuban pine, with the oaks and hickories of the region. Yellow poplar, tupelo, sweet gum, and chestnut are also reported.

In Cuba severe thunderstorms are frequent, and trees are often struck and killed. The pine only is reported ignited. A record of 322 cases, principally in the Province de Oriente, shows liability to stroke in the following order:

Royal palm.
Cuban pine.
Dagamo.
Cocoa palm.
Cedro.
Hobo.
Ceiba.

Caoba.
Baria.
Caguani.
Guasima.
Algaroba.
Almasigo.



FIG. 14.—Chestnut, southeastern New York, one half dismantled, with spiral wounds on limbs.

Lightning is extremely rare in Alaska, and no forest fires are known to have resulted from it.

It does not follow that the trees most liable to ignition by lightning are the ones most responsible for forest fires. Exact figures, however, can not be obtained. While in general one species may be more inflammable than another, the degree of inflammability varies with the locality and season. The tree most often struck and ignited in the West is the western yellow pine, which grows in open, park-like stands, where the fire hazard is small.

A tree may be set on fire by lightning and burn for days without the flames spreading to other trees or to the ground, and if the latter be free from litter, as is often the case in western yellow pine forests, the chances of the fire spreading are small. It is probable that the majority of forest fires caused by lightning striking trees is due to the presence of dry duff, humus, or litter at the base of the tree. Another possibility is that some forest fires are started by lightning striking the ground and igniting the soil cover. Evidence of this, however, is lacking.

Table 4 shows the actual number and percentage of fires on the National Forests caused by lightning in relation to the total number of all fires.

TABLE 4.—*Number and percentage of forest fires caused by lightning on the National Forests in the United States.*

On the National Forests in the State of—	1906		1907		1908		1909		1910		1911	
	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.
Arizona.....			37	26.6	8	26.8	23	17.3	51	27.6	76	44.7
Arkansas.....			(¹)	(¹)	0	.0	3	.8	2	.5	.....	.....
California.....			42	13.8	165	28.8	84	17.6	110	19.9	282	35.4
Colorado.....			3	2.2	10	3.3	10	7.7	36	9.3	19	14.6
Florida.....			(¹)	(¹)	(¹)	(¹)	(¹)	(¹)	1	3.6	.....	.....
Idaho.....			25	14.2	106	31.2	79	8.0	162	21.8	129	32.2
Kansas.....			0	.0	1	33.3	4	100.0	9	100.0	.....	.....
Michigan.....			(¹)	(¹)	(¹)	(¹)	(¹)	(¹)	0	.0	1	.3
Minnesota.....			(¹)	(¹)	0	.0	0	.0	2	1.5	2	.3
Montana.....			13	12.6	66	14.6	44	14.5	124	11.0	54	27.3
Nebraska.....			3	75.0	1	50.0	4	80.0	0	0.0	7	77.8
Nevada.....			0	.0	1	25.0	0	.0	5	62.5	4	33.3
New Mexico.....			4	6.3	7	7.0	12	9.3	43	23.4	18	15.9
North Dakota.....			(¹)	(¹)	(¹)	(¹)	(¹)	(¹)	1	100.0	.....	.....
Oklahoma.....			12	34.3	0	.0	2	15.4	1	33.3	1	50.0
Oregon.....			26	28.9	130	41.4	15	7.5	74	14.9	219	42.0
South Dakota.....			6	3.4	2	1.3	3	4.3	17	8.3	69	31.1
Utah.....			0	.0	0	.0	1	5.9	5	19.2	2	8.3
Washington.....			15	18.3	23	16.9	6	3.7	42	8.2	49	15.1
Wyoming.....			2	5.9	5	25.0	1	3.6	39	24.8	15	33.3
Total.....	261	23.0	176	13.0	555	20.3	294	9.4	724	13.9	947	28.1

¹ No record.

ELECTRIC CONDUCTIVITY OF NATIVE WOODS.

Laboratory experiments with electrical currents can imitate only in a very small degree some of the phenomena of lightning or the potentials which may obtain in the atmosphere. Nevertheless, such experiments are helpful in that they indicate that one theory regarding the action of lightning is more probable than another. In an endeavor therefore to test several theories, a number of laboratory experiments were made in the Forest Service upon pieces of native woods. The size of the specimens used in the experiments was 6 by $\frac{1}{2}$ by $\frac{3}{8}$ inch.

The experiments proved absolutely that electric conductivity is dependent upon water content of the wood. When absolutely dry, none of the specimens showed conductivity, but the resistance of all was practically infinity. The most sensitive galvanometer showed no deflection under a pressure of 300 volts. The delicacy of this test was such that the needle of the galvanometer could be instantly deflected by simply breathing upon the wood while it was in the electric circuit. Through the courtesy of Prof. Louis D. Bliss the tests were repeated in his laboratory and the results previously obtained verified. Prof. Bliss writes:

The conclusion arrived at from these tests was that the nature of the wood itself had nothing to do with its resistance and that the resistance was determined wholly by the amount of moisture which the wood contains.

These determinations confirm the experiment made by du Moncel (see p. 15), that thoroughly dried pieces of wood gave no deflection.

In order still further to test the conductivity of wood, experiments were made with another apparatus constructed for testing the specimens with static electricity, thus producing as nearly as possible by means of a large induction machine the phenomenon of linear lightning. Sparks 18 inches long were induced, representing about 500,000 volts. However, a shorter spark was found to be much more satisfactory (in connection with Leyden jars) for producing single flashes and for lessening the diffusion. This apparatus provided sparks of various lengths between two metal points, and also between a piece of wood arranged so as to approach one of the metal points, until a spark was induced between the wood and the opposite metal point, where the sparks between the two metal points would cease. The distance from the metal point to the wood was then measured, with the results given in Table 5.

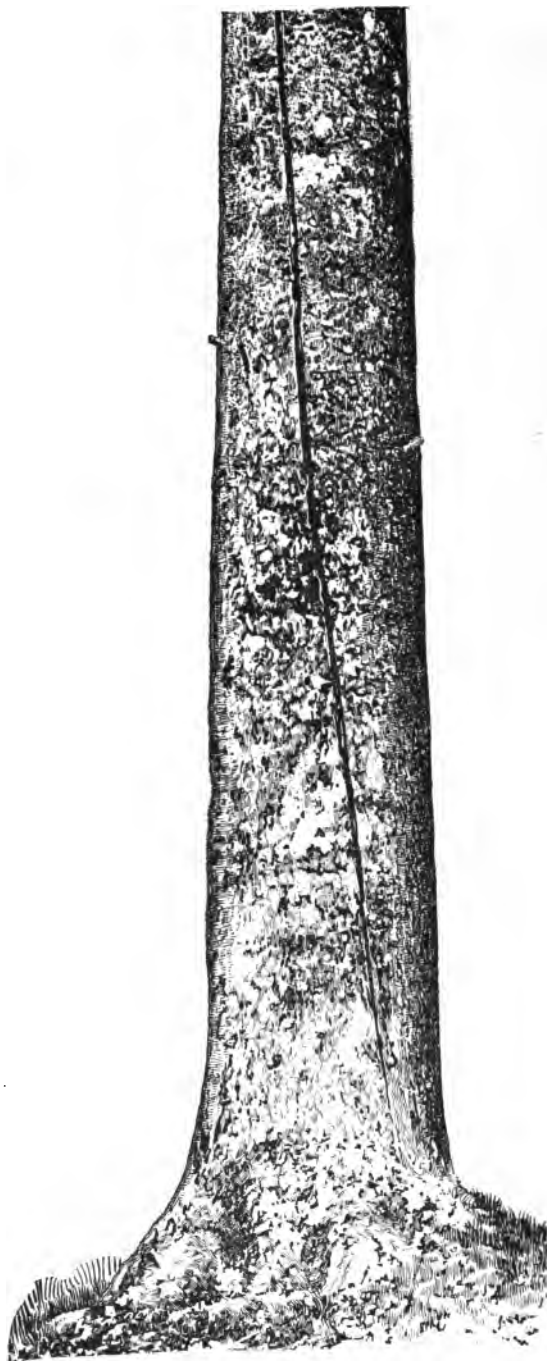


FIG. 15.—Beech, Kentucky, slightly wounded.

TABLE 5.—Length of static electric spark flashed to specimens of wood, being equal to a spark of 3 inches through dry air, between metal points.

Names of wood.		After 3 days in the humidior.	After drying for 2 days.	After soaking 1 day and having surplus water removed.
Common name.	Scientific name.			
		<i>Inches.</i>	<i>Inches.</i>	<i>Inches.</i>
Basswood.....	Tilia americana.....	2.79	0.00	1.79
Macnab cypress.....	Cupressus macnabiana.....	2.71	.00	1.70
Alpine fir.....	Abies lasiocarpa.....	2.70	.00	2.33
Noble fir.....	Abies nobilis.....	2.60	.00	2.06
Aspen.....	Populus tremuloides.....	2.60	.00	2.20
Tulip tree.....	Liriodendron tulipifera.....	2.60	.00	2.07
Box (foreign).....	Buxus sempervirens.....	2.42	.00	2.25
White ash.....	Fraxinus americana.....	2.41	.00	2.57
Ebony (foreign).....	Diospyros ebenus.....	2.40	.00	1.71
Oregon ash.....	Fraxinus oregona.....	2.40	.00	1.41
Alligator juniper.....	Juniperus pachyphloea.....	2.40	.00	2.24
White pine.....	Pinus strobus.....	2.35	.00	2.10
Western white pine.....	Pinus monticola.....	2.05	.00	2.06
Loblolly pine.....	Pinus taeda.....	1.86	.00	2.23
Mexican walnut.....	Juglans rupestris.....	1.84	.00	2.07
Cottonwood.....	Populus deltoides.....	1.75	.00	2.17
Shagbark (hickory).....	Hicoria ovata.....	1.74	.00	2.19
Pecan (hickory).....	Hicoria pecan.....	1.72	.00	2.43
Slippery elm.....	Ulmus pubescens.....	1.65	.00	2.04
Sugar maple.....	Acer saccharum.....	1.64	.00	2.38
California white oak.....	Quercus lobata.....	1.50	.00	2.20
Western birch.....	Betula occidentalis.....	1.46	.00	2.11
White alder.....	Alnus rhombifolia.....	1.43	.00	2.10
California juniper.....	Quercus californica.....	1.36	.00	2.23
Lowland fir.....	Abies grandis.....	1.33	.00	2.59
Western larch.....	Larix occidentalis.....	1.26	.00	2.16
Black cottonwood.....	Populus trichocarpa.....	1.21	.00	2.19
Sugar pine.....	Pinus lambertiana.....	1.20	.00	2.01
White oak.....	Quercus alba.....	1.09	.00	2.25
California sycamore.....	Platanus racemosa.....	1.07	.00	2.22
Western hemlock.....	Tsuga heterophylla.....	1.05	.00	2.17
Oregon maple.....	Acer macrophyllum.....	.96	.00	2.19
Engelmann spruce.....	Picea engelmanni.....	.94	.00	2.29
Nuttall willow.....	Salix nuttallii.....	.93	.00	2.01
Sitka spruce.....	Picea sitchensis.....	.87	.00	2.10
One-seed juniper.....	Juniperus monosperma.....	.85	.00	2.09
Incense cedar.....	Libocedrus decurrens.....	.45	.00	2.27
Douglas fir (red).....	Pseudotsuga taxifolia.....	.47	.00	2.33
Western yellow pine.....	Pinus ponderosa.....	.00	.00	2.03
White fir.....	Abies concolor.....	.00	.00	2.03
Red cedar.....	Thuja plicata.....	.00	.00	2.23
Redwood.....	Sequoia sempervirens.....	.00	.00	2.03
Yellow birch.....	Betula lutea.....	.00	.00	2.19
Black walnut.....	Juglans nigra.....	.00	.00	2.10
Water oak.....	Quercus nigra.....	.00	.00	2.19
Yellow cedar.....	Chamaecyparis nootkatensis.....	.00	.00	2.04
Chestnut.....	Castanea dentata.....	.00	.00	2.00
Beech.....	Fagus atropurpurea.....	.00	.00	2.12

It is evident from these results that dry wood is a nonconductor, for the spark refused to jump to any but three specimens (pecan, slippery elm, and valley oak), which gave a spark so short that it could not be measured. It was evident, however, that these woods contained a small amount of moisture, possibly retained from the humidior, as it was found that by allowing them to spark for a short time they became nonconductors, i. e., they became perfectly dry. These results, represented by 0.00 inch, and corresponding to 0.00 degree of deflection, agree with those obtained with the galvanometer by Prof. Bliss and by du Moncel.

Experiment with the static apparatus was continued to determine whether several specimens of wood from different trees of the same

species would give different results. It appears that they do, but that the divergence is not marked, unless there is a visible difference in the character of the wood. The results of this experiment, the specimens having been soaked as before, are given in Table 6.

TABLE 6.—*Behavior of wood under experiments with static current.*

Name of wood.	Length of spark induced.	Character of wood.
	<i>Inches</i>	
Aspen (<i>Populus tremuloides</i>).....	2.20	Both of the same grain.
	2.15	
	2.24	
Alligator juniper (<i>Juniperus pachyphloea</i>).....	2.33	Do.
	2.31	
	2.06	With very crooked grain.
	2.06	
White pine (<i>Pinus strobus</i>).....	2.25	Both sapwood of same grain.
	2.25	
	2.36	Sapwood with small amount of heartwood.
	2.25	
Western white pine (<i>Pinus monticola</i>).....	2.14	Slightly infected with fungus.
	2.15	
	2.19	Heartwood.
	2.50	
Black cottonwood (<i>Populus trichocarpa</i>).....	2.29	Sapwood.
	2.50	
Engelmann spruce (<i>Picea engelmanni</i>).....	2.00	Similar grain and structure.
	2.20	
Chestnut (<i>Castanea dentata</i>).....	2.03	Radially cut sapwood.
	2.11	
	2.18	Radially cut heartwood.
	2.18	
Western yellow pine (<i>Pinus ponderosa</i>).....	2.30	Fine grained.
	2.30	
	1.80	Coarse grained.
	2.15	
Douglas fir (<i>Pseudotsuga taxifolia</i>).....	2.33	Radially cut sapwood.
	2.38	
	2.73	Fine-grained heartwood.
	2.73	
	2.30	Slightly crooked sapwood.
	2.38	
	2.73	Straight-grained heartwood.
	2.73	
	2.30	Fine-grained sapwood.
	2.38	
	2.73	Very pitchy, straight, coarse grained and red.
	2.73	
	2.15	Fine grained and "yellow."
	2.33	
	2.38	"Red" coarse grained
	2.73	
	2.73	"Yellow" fine grain, slightly crooked.
	2.73	

¹ This remarkable divergence necessitated repetition of the experiments in which it was found that if these specimens were left in the apparatus for a few moments that their conductivity decreased, and doubtless from the loss of moisture.

Fundamentally the manifestations of lightning are subject to law, but as the phenomena produced by lightning are variable, this must be because some important factor is variable. Thus, the conductivity of wood, or of a tree, depends upon moisture content, and this factor is subject to great changes. A heavy driving rain, such as accompanies the average thunderstorm, can so wet any tree that it will become, for the time being, an excellent conductor, which is all that is required. Up to that time the tree might have been in itself a poor conductor. Thus, though the moisture content of wood, particularly within the outermost layer of growth in a living tree, adds to the variability of induction, even the most resinous of trees, with lowest moisture content, can, under a heavy rain, become a splendid conductor in a moment's time. Because of this, and the fact that the form of the most efficient lightning rod, with its branches at both ends, resembles that of a tree, it is evident that any tree may be struck by lightning.



FIG. 16.—Utah juniper, southeastern Idaho, shattered and ignited by lightning.

SUMMARY OF CONCLUSIONS.

1. Trees are the objects most often struck by lightning because: (a) They are the most numerous of all objects; (b) as a part of the ground they extend upward and shorten the distance to a cloud; (c) their spreading branches in the air and spreading roots in the ground present the ideal form for conducting an electrical discharge to the earth.

2. Any kind of tree is likely to be struck by lightning.

3. The greatest number struck in any locality will be of the dominant species.

4. The likelihood of a tree being struck by lightning is increased: (a) If it is taller than surrounding trees; (b) if it is isolated; (c) if it is upon high ground; (d) if it is well (deeply) rooted; (e) if it is the best conductor at the moment of the flash; that is, if temporary conditions, such as being wet by rain, transform it for the time from a poor conductor to a good one.

5. Lightning may bring about a forest fire by igniting the tree itself, or the humus at its base. Most forest fires caused by lightning probably start in the humus.

APPENDIX.

LIST OF TREES IN THE BULLETIN.

<i>Abies amabilis</i>	Amabilis fir.
<i>Abies arizonica</i>	Arizona cork fir.
<i>Abies concolor</i>	White fir.
<i>Abies grandis</i>	Lowland fir.
<i>Abies lasiocarpa</i>	Alpine fir.
<i>Abies magnifica</i>	Red fir.
<i>Abies nobilis</i>	Noble fir.
<i>Abies shastensis</i>	Shasta fir.
<i>Acer campestre</i>	Field maple (foreign).
<i>Acer dasycarpum</i> (saccharinum).....	Silver maple (foreign).
<i>Acer macrophyllum</i>	Oregon maple.
<i>Acer negundo</i>	Boxelder.
<i>Acer platanoides</i>	Norway maple (foreign).
<i>Acer pseudoplatanus</i>	Sycamore maple (foreign).
<i>Acer saccharum</i>	Sugar maple.
<i>Aesculus hippocastanum</i>	Horse chestnut (foreign).
<i>Ailanthus glandulosa</i>	Ailanthus (foreign).
<i>Alnus glutinosa</i>	European alder (foreign).
<i>Alnus rhombifolia</i>	White alder.
<i>Bursera simaruba</i>	Almasigo (foreign).
<i>Betula alba</i>	White birch (foreign).
<i>Betula lutea</i>	Yellow birch.
<i>Betula occidentalis</i>	Western birch.
<i>Buxus sempervirens</i>	Box (foreign).
<i>Castanea dentata</i>	Chestnut.
<i>Catalpa kaempferi</i>	Japanese catalpa (foreign).
<i>Cedrela odorata</i>	Cedro (foreign).
<i>Chamaecyparis nootkatensis</i>	Yellow cedar.
<i>Cocos nucifera</i>	Cocoa palm (foreign).
<i>Colutea cruenta</i>	Bladder-senna (foreign).
<i>Copaifera mopane</i>	Mopane (foreign).
<i>Cordia nutida</i>	Baria (foreign).
<i>Cornus sanguinea</i>	European red-osier dogwood (foreign).
<i>Corylus avellana</i>	European hazel or filbert (foreign).
<i>Crataegus monogyna</i>	Hawthorne (foreign).
<i>Cupressus arizonica</i>	Arizona cypress.
<i>Cupressus macnabiana</i>	Macnab cypress.
<i>Cytisus laburnum</i>	Golden chain (foreign).
<i>Diospyros ebenus</i>	Ebony (foreign).
<i>Eleagnus angustifolia</i>	Wild olive.
<i>Eriodendron anfractuosum</i>	Ceiba (foreign).